Artificial Dielectrics and Photonic Crystals for STAB Elements: the Receiver

STAB Kick-off Meeting
August 8-9, 2000

Ultrafast and Nanoscale Optics Group
UNIVERSITY OF CALIFORNIA, SAN DIEGO

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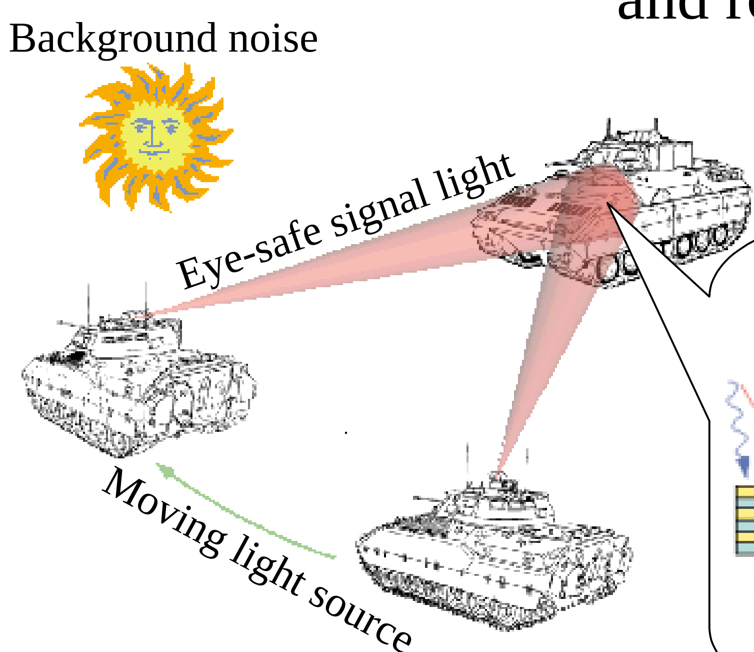
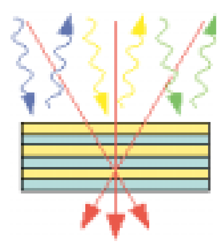
Motivation: Laser communications for future information-rich battlefield environments

Key Element:
Efficient, compact/light weight, low cost, standardized, manufacturable, and robust ***receiver structures***



Requirements:



- Low signal loss
- Strong background noise rejection
- Chip-scale integration
- Wide field of view (no moving parts required)

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Outline

- **Motivation**
- **Approach:** near-field phenomena in resonant nanostructures
  - –Implementation with photonic crystals
  - –Advancement of design and modeling tools
  - –Development of nano-fabrication techniques
  - –Development of characterization methods and tools
- **Background**
- **Research Plan**
- **Preliminary Study**
  - –Wide field of view/narrowband receiver structure
  - –Optical field concentration in nanostructures
  - –Subwavelength inter-digital electrodes
  - –Research on the fabrication techniques
- **Summary**

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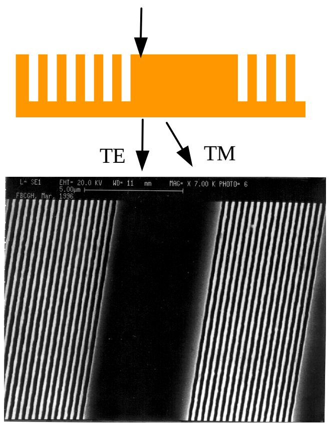
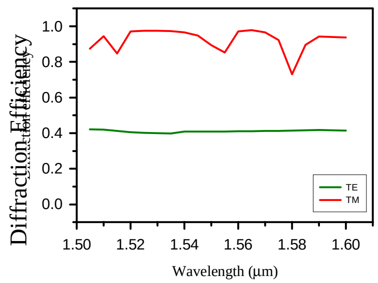
Artificial Dielectric Optical Nanostructures

DARPA

Form Birefringent Computer Generated Hologram :

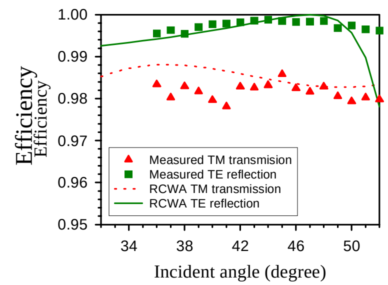
Multi-functionality and arbitrary phase profile

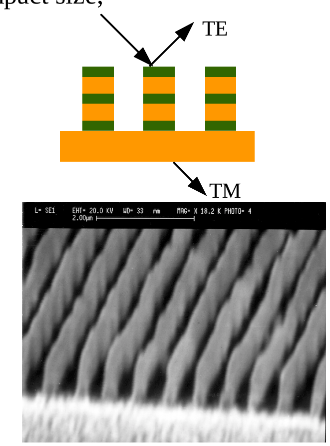




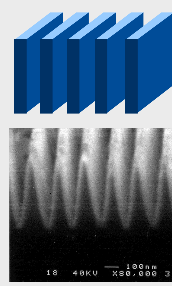
Anisotropic Spectral Reflectivity Polarization Optics :

Large spectral and angular bandwidth, compact size, and normal incident operation



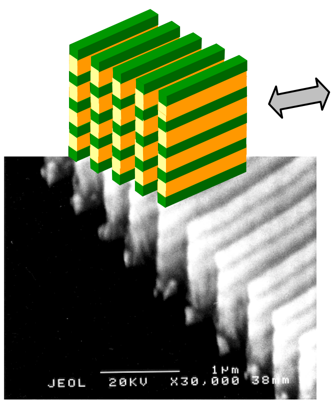


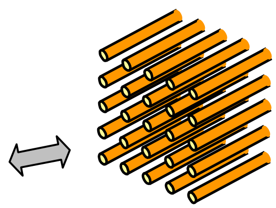
Near-field interactions modify bulk material properties



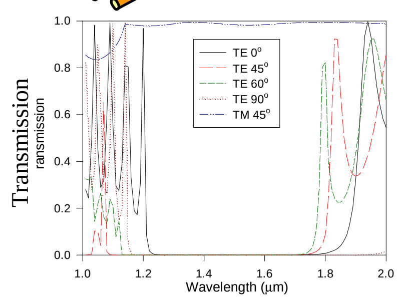
Experimental example* :
Material : GaAs
Incident wavelength = 920 nm
Grating period = 200 nm
Grating depth = 490 nm
Phase difference $\Delta\phi$ = 162.5°
=> $\Delta n/n$ = 0.47

Photonic Crystal :



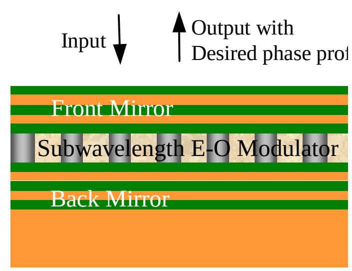


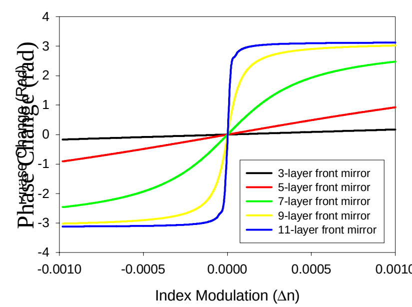
3-material photonic crystal



Near Field Programmable Diffractive Optical Element :

Low voltage, compact size and programmability





fabricated in collaboration with Prof. Axel Scherer, Caltech

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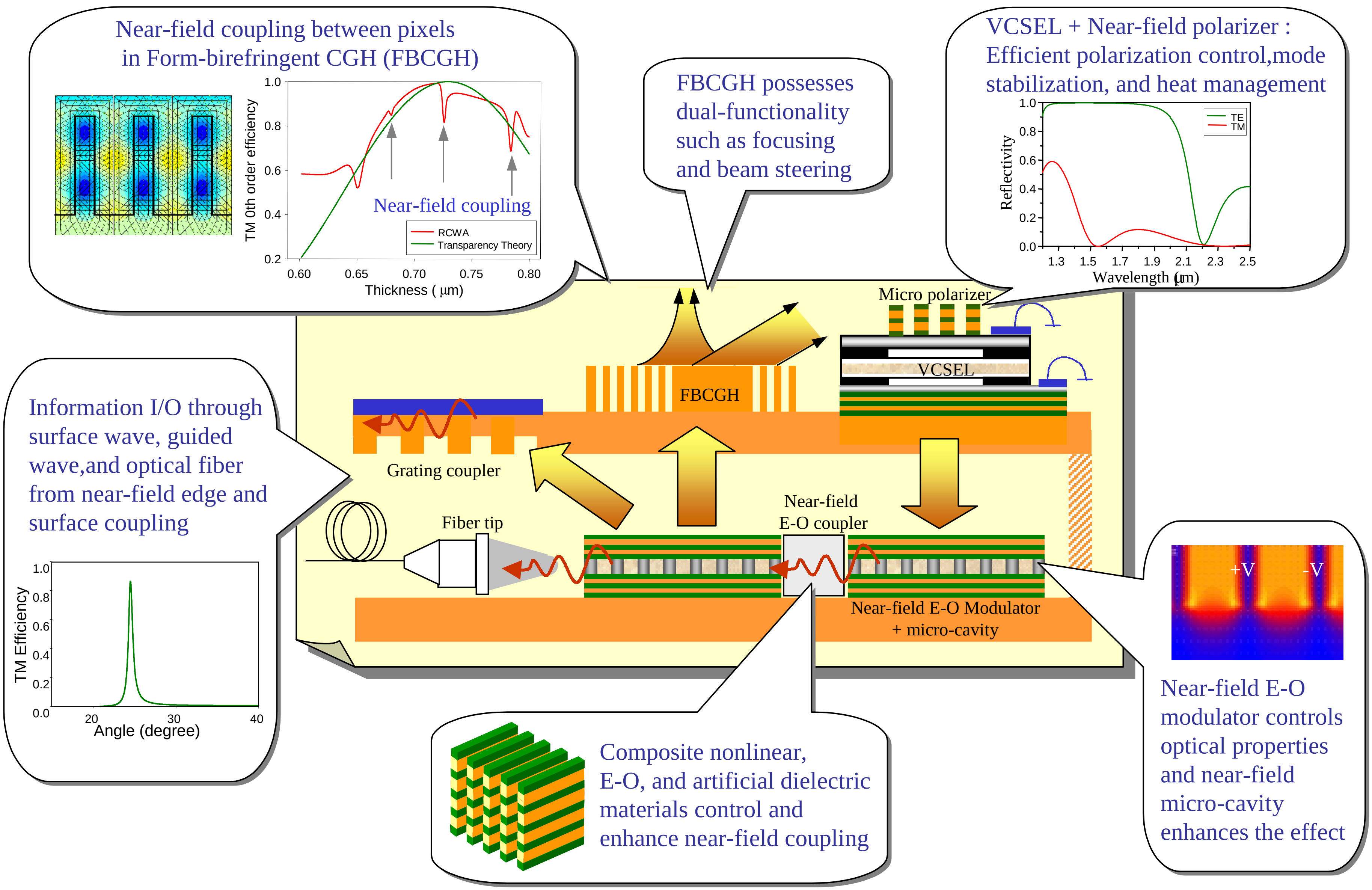
Photonic Integrated Chips

DARPA



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Features and Advantages of the Artificial Dielectric Receiver Structures

- **Large Field of View and Narrow-band Color Selectivity**
  - structures intrinsically exhibit sharp frequency resonance in broad reflection band

- **Design Flexibility**
  - easily adapt to a variety of constituent materials and performance objectives

- **High Detection Efficiency and Gain**
  - resonant cavities
  - optical field concentrations
  - subwavelength electrode separation

- **Fast Time Response**
  - subwavelength detection elements -> small total capacitances

- **Single Chip Solution**
  - compatible with VLSI fabrication technology (materials and process)

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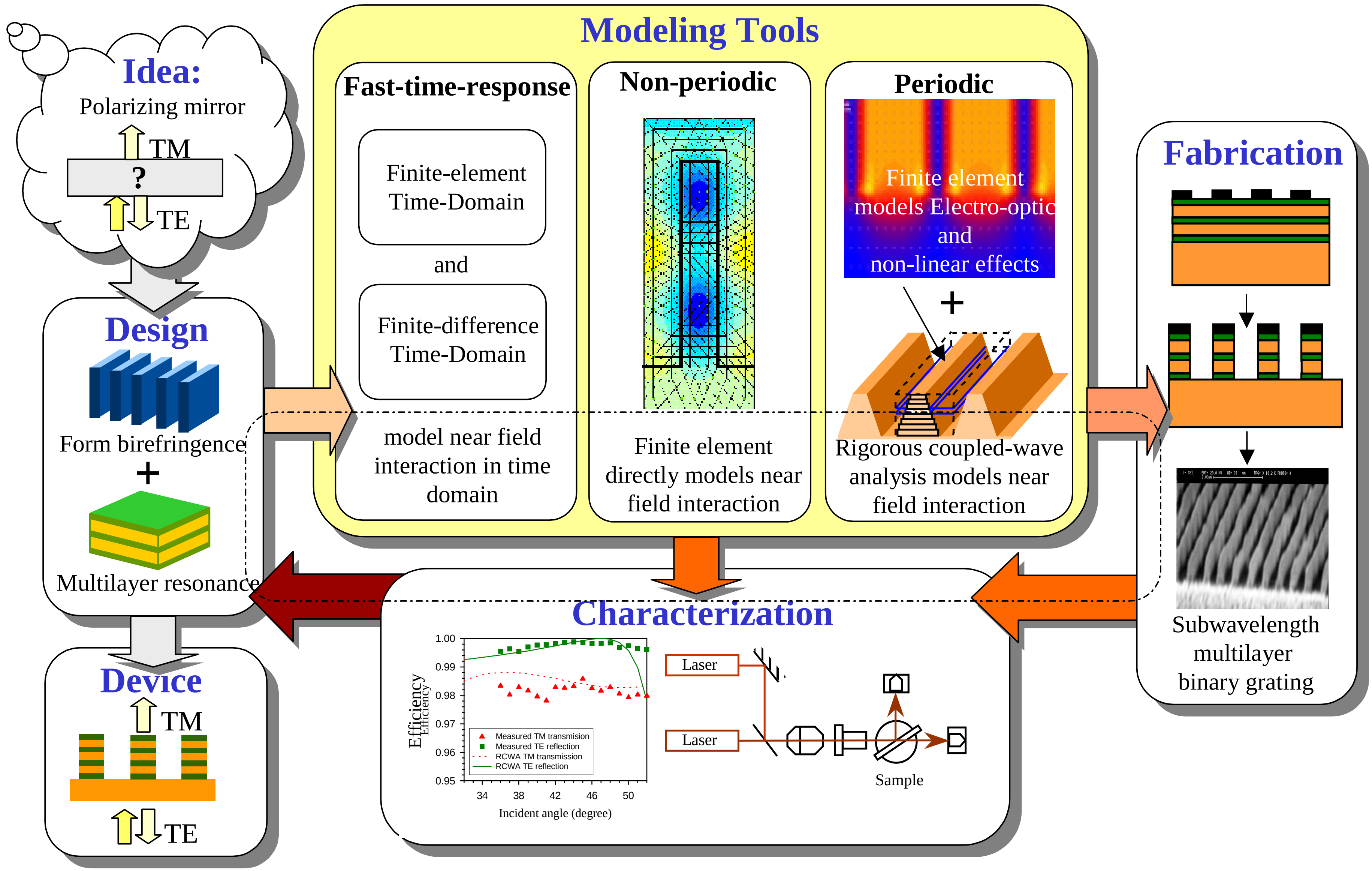
Nanophotonics: Approach



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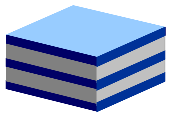
Near-field Resonant Nanostructure: Polarization-Selective Beam Splitter (PBS)

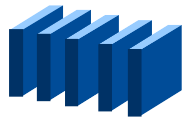
DARPA

Design Principle



Multilayer Reflectivity

+



Form Birefringence

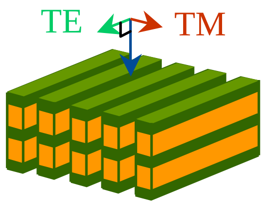
Device Modeling

Each polarization sees a different multilayer structure

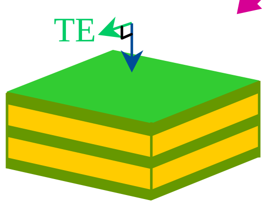
n_{Si} = 3.48

n_{SiO2} = 1.44

Ratio = 2.42



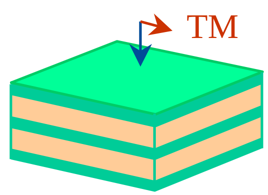
Grating period = 0.6 μm
Duty cycle = 0.5



$n_{TE,Si}$ = 3.25

$n_{TE,SiO2}$ = 1.26

Ratio = 2.58



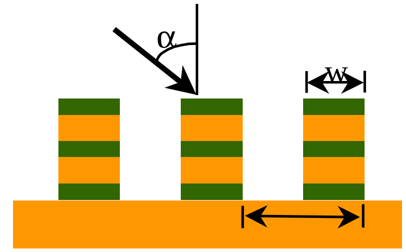
$n_{TM,Si}$ = 1.71

$n_{TM,SiO2}$ = 1.18

Ratio = 1.45

Estimated by 2nd Order Effective Medium Theory for wavelength = 1.5 μm

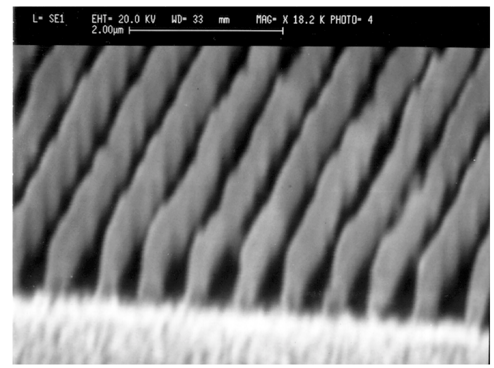
Design, Fabrication & Characterization

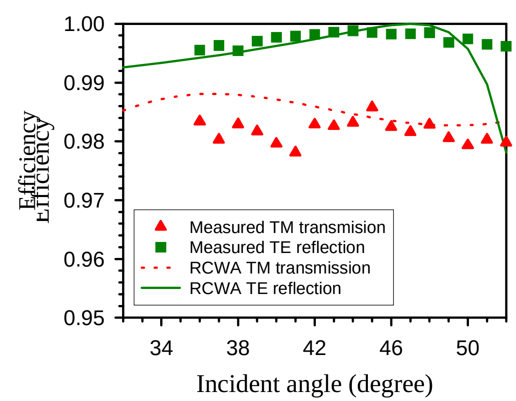


F=w/Λ = 0.5 Λ=0.6μm

Si d_{Si} = 0.13 μm

SiO_2 d_{SiO2} = 0.26 μm





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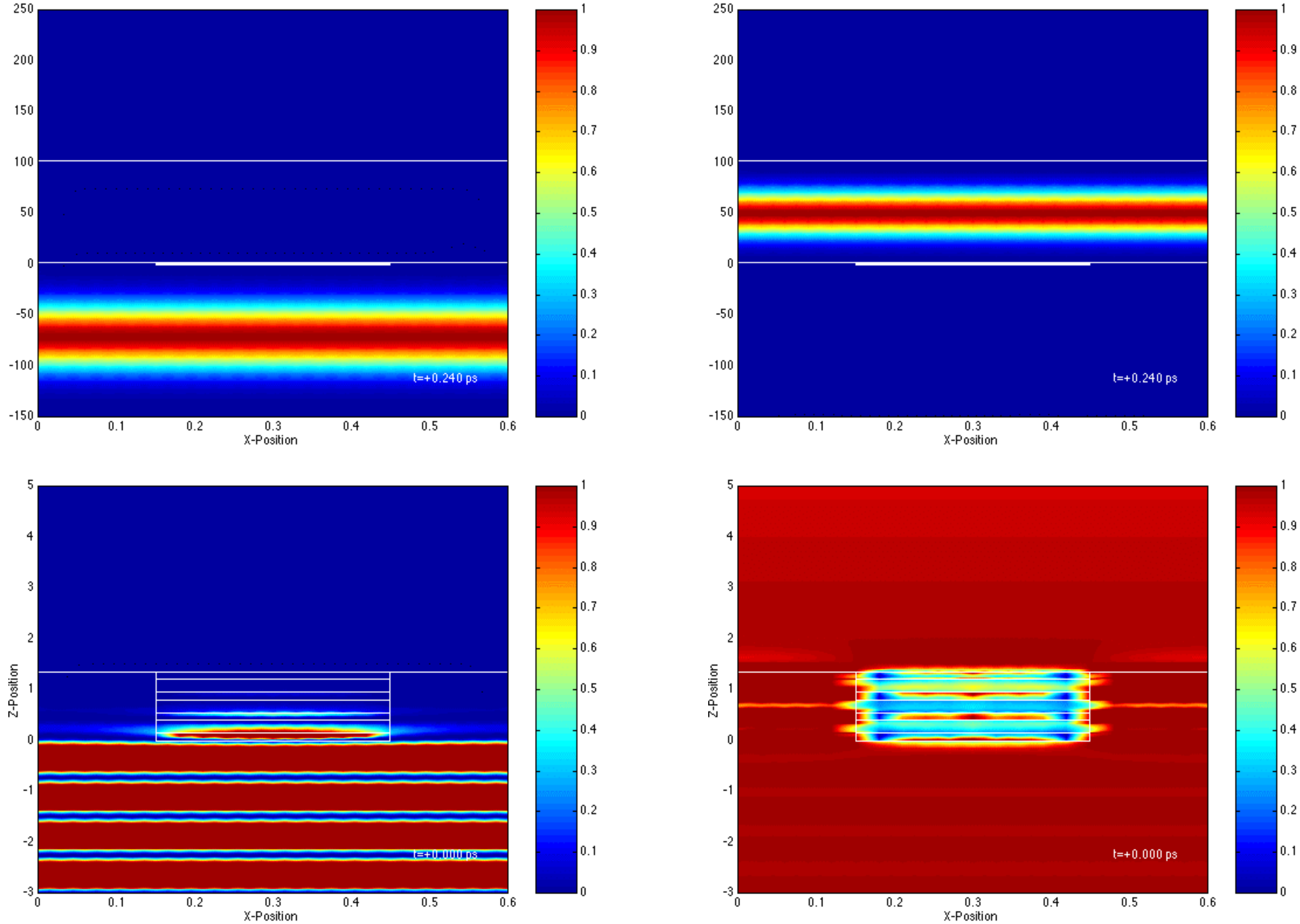
Visualization of Ultrashort Pulse Propagation in Nanostructured PBS

TE Polarization

TM Polarization

Wide view

Zoom view



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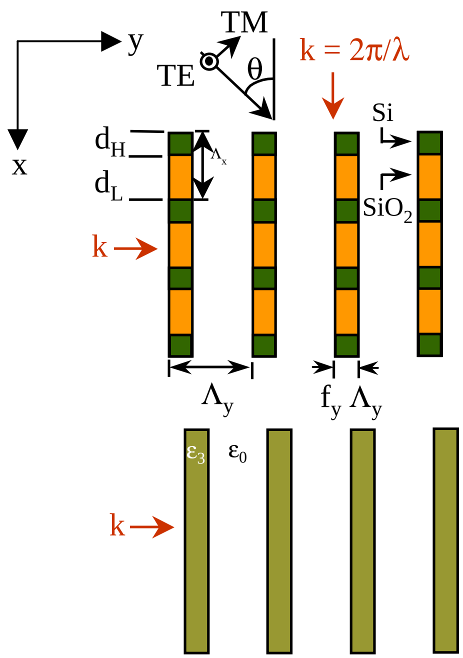
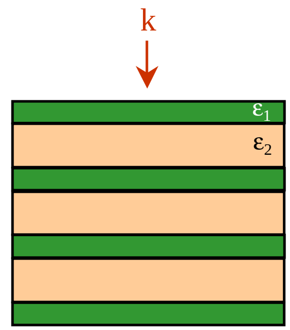
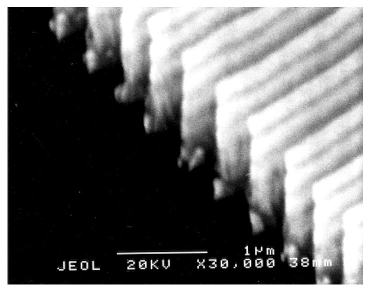
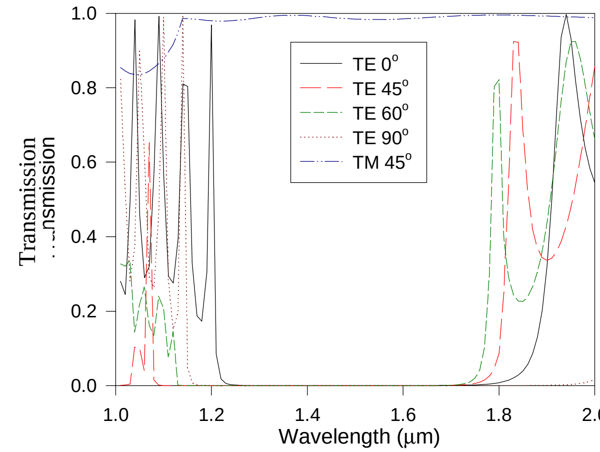
2-D Polarization-Selective Photonic Crystal



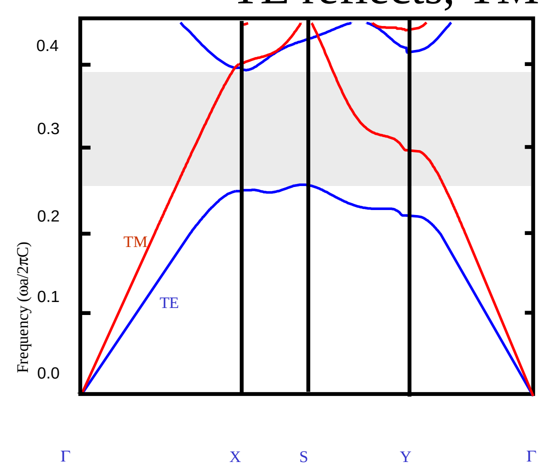


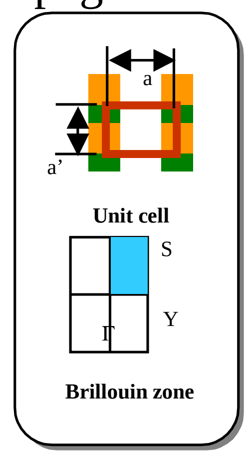


Large frequency bandgap



Large angular range where TE reflects, TM propagates





Calculated by Rigorous coupled-wave analysis

Design parameters

$d_H = f_x \Lambda_x$ $\qquad \sqrt{\varepsilon_1} f_x \Lambda_x = \sqrt{\varepsilon_2}(1-f_x)\Lambda_x = \lambda/4$

$d_L = (1-f_x)\Lambda_x$ $\qquad \sqrt{\varepsilon_0}(1-f_y)\Lambda_y = \sqrt{\varepsilon_3} f_y \Lambda_y = \lambda/4$

$\varepsilon_0 = 1.00$
$\varepsilon_1 = 5.99$
$\varepsilon_2 = 1.32$
$\varepsilon_3 = 6.88$

$f_x = 0.319$
$f_y = 0.276$
$\Lambda_x = 0.487\mu m$
$\Lambda_y = 0.526\mu m$